Technical Note

Meniscal Radial Tears: A Classification System Based on Tear Morphology

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Abstract: Appropriate management of radial meniscal tears is complex, with continued efforts focused on optimizing diagnostic methods for identification to help dictate treatment, especially as surgical indications for repair have expanded, coupled with improvements in surgical techniques and instrumentation. Currently, no standardized classification system for radial meniscal tears exists, limiting the ability to accurately characterize injury patterns and guide surgical decision-making.

Meniscal tears remain one of the most common knee injuries, affecting patients of all ages and activity levels.[1,2] The menisci play a crucial role in maintaining homeostasis within the knee joint, preserving tibiofemoral congruency, joint stability, dynamic load distribution, and proprioception.[3,4] As a result, operative intervention is often recommended in patients with meniscal tears and continued symptoms following a trial of nonoperative management. Despite providing short-term pain relief, debridement of meniscal tears, especially those involving >60% of the meniscal width,[4] results in inferior biomechanical effects,[5,6] perpetuating a meniscal-deficient state and increasing the risk for early osteoarthritis (OA) development.[7-9] Meanwhile, tissue preservation through meniscal repair has been reported to restore biomechanical load distribution within the affected compartment,[5,6] decreasing the risk for early chondral wear and degeneration.[10,11] As such, the popularity of meniscal repair procedures has increased when compared to meniscal debridement in appropriately selected patients.[12]

Radial tears of the meniscus are unique due to their perpendicular orientation to the meniscal axis, effectively disrupting the circumferential collagenous fibers at the periphery of the menisci. Arising from the central region and extending to a variable extent to the periphery, radial tears may occur in all zones within the medial and lateral menisci secondary to acute traumatic or chronic degenerative processes.[4] When present, radial tears lead to increased joint contact pressures,

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resulting in a higher risk for chondral damage, as well as the potential for increased meniscal extrusion relative to longitudinal and horizontal meniscal tears.[13,14] As such, proper identification and treatment for radial meniscal tears are essential to preserve knee function and ensure the longevity and health of the knee. When indicated, decision-making during operative management is dictated based on several patient-specific (patient age, activity level, compliance, weight, lower extremity mechanical alignment) and tissue-specific (meniscal tissue quality, extent of degenerative changes to chondral surfaces) factors. There remains a substantial degree of heterogeneity in the reporting of outcomes in patients with radial tears of the meniscus, limiting the ability to pool results between investigations to better understand optimal indications and techniques for surgical repair. To improve homogeneity in the reporting of outcomes in patients with radial tears, establishing a standardized classification of tear morphology is essential to ensure consistency in nomenclature and treatment.

The aim of the current article is to introduce a comprehensive classification system to better characterize radial tears of the menisci, along with the senior author's (J.C.) preferred approach to the management of each tear type.

Classification

The proposed classification system based on radial tear morphology is illustrated in Figure 1 and Table 1.

Treatment Algorithm

The senior author's preferred approach to the management of each tear type is illustrated in Figure 2 and Table 2.

Patient Positioning and Preparation

Following the induction of general anesthesia, the patient is placed in the supine position, ensuring that all bony prominences are well padded. A nonsterile pneumatic tourniquet is placed on the upper thigh. A lateral post is positioned to allow for effective valgus positioning of the knee to improve visualization of the medial compartment. The patient is given appropriate antibiotics for prophylaxis against infection. Examination under anesthesia is performed on the bilateral knees to assess the range of motion, patellar mobilization, and knee stability in the anterior/posterior and medial/lateral planes. The operative leg is then prepped and draped in a standard sterile fashion. The leg is exsanguinated using an Esmarch and the tourniquet is inflated.

A standard anterolateral portal is created, and a 30-degree arthroscope (Smith & Nephew) is inserted. An anteromedial portal is then created under arthroscopic visualization using a spinal needle. Diagnostic arthroscopy is then performed, evaluating the integrity of the chondral surfaces of the patellofemoral as well as medial and lateral tibiofemoral joint spaces. The menisci are visualized, and an arthroscopic probe is used to inspect the meniscus and determine the presence of any tearing or instability (Table 3). If a tear is

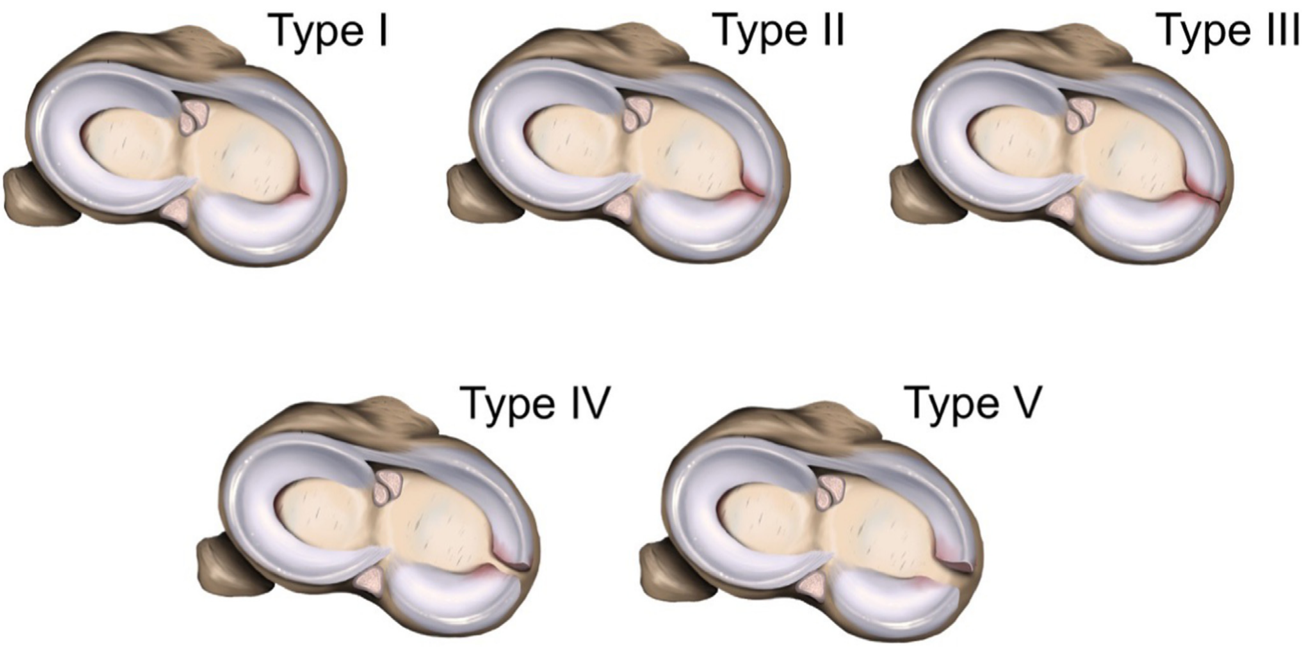

Fig 1. Illustrations of the left knee depicting meniscal radial tear patterns based on morphology: partial stable radial tear extending to the white-white zone (type I), partial unstable radial tear extending to the red-white zone (type II), complete radial tear without gapping (type III), complete radial tear with ≤3 mm of gapping (type IV), and complete radial tear with >3 mm of gapping (type V).

Table 1. Classification of Radial Tears of the Medial and Lateral Meniscus Based on Tear Morphology

Type	Description
I	Partial radial tear extending to the white-white zone
II	Partial radial tear extending to the red-white zone
III	Complete radial tear with no gapping
IV	Complete radial tear with ≤3 mm of gapping
V	Complete radial tear with >3 mm of gapping

identified, the location (posterior root, posterior horn, midbody, anterior horn, anterior root), size, and type (radial, horizontal, vertical, degenerative, etc.) of the tear are determined and recorded. For radial tears, tear morphology is classified based on the proposed classification system.

Type I: Partial Radial Tear in the White-White Zone

Type I tears are characterized as incomplete radial tears, representing stable, partial tears that originate from the inner border of the meniscus and extend peripherally to the white-white zone. In the presence of a type I tear, partial meniscectomy is recommended secondary to the low healing potential and avascular nature of the torn meniscus. The free margins of the menisci are gently debrided using a combination of an arthroscopic shaver and biter until a smooth border and stable rim are achieved (Video 1).

Type II: Partial Tear in the Red-White Zone

Type II tears consist of incomplete radial tears that extend from the inner border to the red-white zone of the meniscus. As the red-white zone of the meniscus possesses a viable blood supply, increasing the potential for successful healing, meniscal repair is suggested for type II tears in the absence of degenerative tissue tearing or advanced chondral changes (modified Outerbridge ≥3) within the affected compartment. The borders of the torn meniscus are gently debrided to remove any frayed tissue using an arthroscopic shaver, and meniscal edges may then be rasped. Based on the location of the meniscal tear (posterior horn, midbody, anterior horn), an outside-in, all-inside, or inside-out approach can be used for meniscal repair. For an all-inside repair, the implant (Fast Fix Flex; Smith & Nephew) is inserted into the joint carefully using a skid and placed perpendicularly across the tear in a horizontal mattress fashion. After removing the device from the joint, a knot pusher is used to tension the knot, ensuring the meniscal edges re-establish continuity, after which the suture is cut. Additional implants are placed in an identical manner parallel to the first implant to create a stable horizontal mattress configuration. Inside-out and outside-in repairs have been previously described with their respective approaches.[15-17]

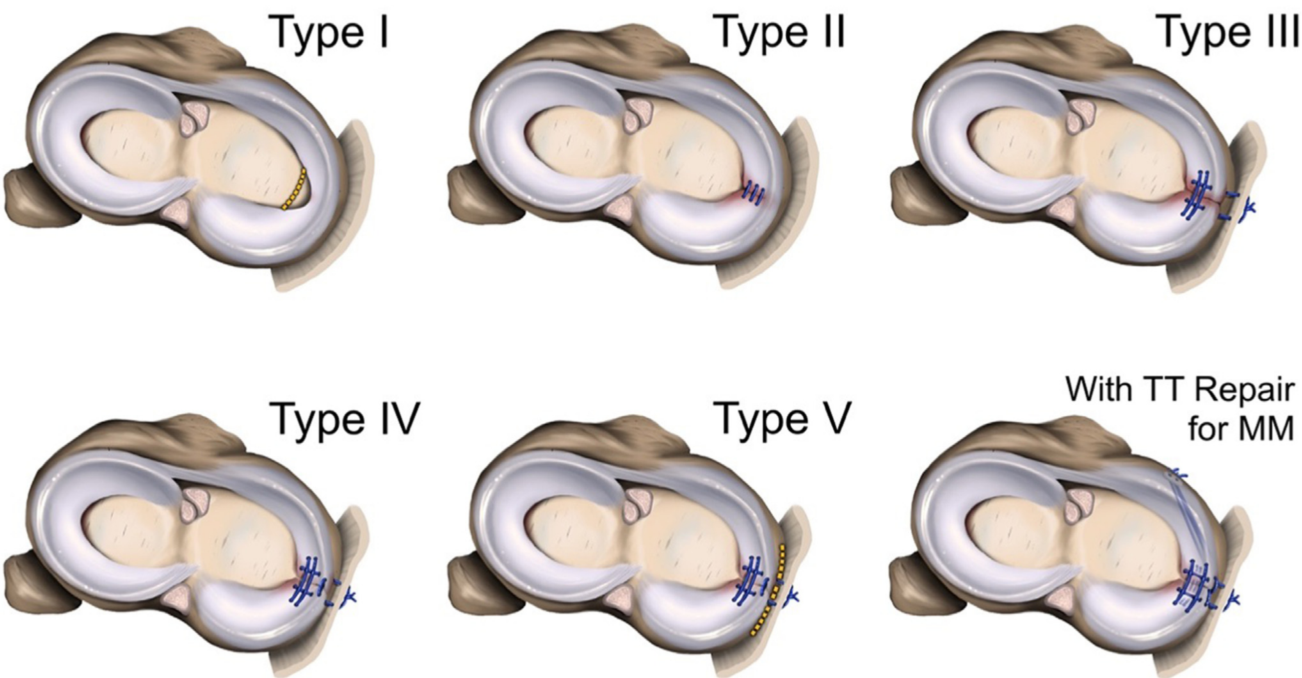

Fig 2. Illustrations of the left knee showing the senior author's preferred repair configurations based on radial tear patterns. Type I: Partial meniscectomy. Type II: Side-to-side repair stitches. Type III: Hashtag repair. Two vertical "rip-stop" mattress sutures and multiple side-to-side repair stitches. Type IV: Reduction stitch to approximate the leaflets followed by a hashtag repair. Type V: Release of the anterior and posterior meniscocapsular attachments to aid in further mobilization and then a reduction stitch, followed by a hashtag repair. A transtibial tunnel can be used for type III, IV, and V tears involving the medial meniscus.

Table 2. The Senior Author's Preferred Approach to the Management of Each Tear Type

Type	Tear	Treatment
I	Partial radial tear extending to the white-white zone	Partial meniscectomy
II	Partial radial tear extending to the red-white zone	Side-to-side repair
III	Complete radial tear with no gapping	Hashtag repair*
IV	Complete radial tear with ≤3 mm of gapping	Reduction stitch and hashtag repair*
V	Complete radial tear with >3 mm of gapping	Release, reduction stitch, and hashtag repair*

*For any complete medial meniscus radial repairs (types III, IV, and V), a transtibial tunnel can be created to centralize the meniscus.

Type III: Complete Radial Tear With No Gapping

Type III tears are characterized by the presence of complete radial tears that reach the meniscocapsular junction, effectively dividing the meniscus into separate anterior and posterior fragments, without any displacement or gapping between fragments.

Similar to type II tears, the senior author's preferred treatment for type III tears in the absence of degenerative meniscal edges or advanced chondral degeneration is surgical repair. The meniscal edges are debrided, and a rasp is used to prepare the torn edges. Repair is performed with either an all-inside or inside-out repair technique consisting of a horizontal mattress configuration with 2 vertical rip-stop sutures (hashtag configuration). The vertical mattress sutures are placed first, tensioned, and then cut, effectively avoiding cutting through the horizontal mattress sutures by serving as a "rip-stop." The horizontal mattress sutures are then placed, beginning at the more posterior leaflet, ensuring the sutures are placed further from the tear than the vertical mattress sutures. The horizontal mattress sutures are then tensioned, avoiding over-reduction, and then cut. Additional horizontal mattress sutures are then placed in parallel to secure the repair construct.

Type IV: Complete Radial Tear With ≤3 mm of Gapping

Type IV tears are described based on the presence of a complete radial tear to the meniscocapsular junction with fragment gapping no greater than 3 mm. In patients without degenerative meniscal fraying or advanced chondral changes, meniscal repair is recommended. The proposed treatment for type IV lesions begins by ensuring the meniscal fragments can be reduced to their anatomic position. Scarring for type IV tears is often not encountered due to the limited degree of displacement, as such releasing along the meniscocapsular junction is often not necessary. An arthroscopic rasp or shaver may be gently used to prepare the torn meniscal edges. An all-inside or inside-out meniscal repair implant is then used to reduce the fragment edges to their anatomic position. The needle is inserted in one of the meniscal ends without passing through the capsule. The needle is used as a "joystick" to mobilize the fragment into an anatomic position, after which the needle or the implant is inserted through the capsule to secure the meniscus in an appropriate position along both the anterior and posterior leaflets.

The suture is then tensioned using the knot pusher and cut and/or tied on the capsule (inside-out). Then the hashtag configuration can be performed as previously described. Two vertical mattress rip-stop sutures are then inserted (and tied to the opposite rip-stop suture on the capsule), followed by the appropriate number of horizontal mattress sutures to create a stable construct.

Type V: Complete Radial Tear With >3 mm of Gapping

Type V tears are characterized by the presence of a complete radial tear with a gap measuring greater than

Table 3. Pearls and Pitfalls

Pearls
- Appropriate portal placement is vital for sufficient visualization, and if necessary, accessory portals should be created to improve visualization and accuracy for implant placement.
- Appropriate visualization is necessary to allow accurate tear identification and classification to ensure the appropriate repair technique is used.
- In the case of a tight medial compartment obscuring visualization, a percutaneous superficial medial collateral ligament lengthening procedure should be performed.
- Vertical mattress sutures placed parallel to the tear are vital to ensure an appropriate "rip-stop" is placed for sutures placed horizontally across the torn meniscal edges to minimize the risk of suture cut-out, especially in poorer-quality meniscal tissue.
- Rasping of the torn edges should be used to prepare the tear site for repair by removing scar tissue and stimulating the vascularity in the peripheral aspect of the tear.
- When meniscal edges are separated, as in the case of type IV and V tears, mobilization of the anterior and posterior fragment should be performed along the meniscocapsular junction of the tear to achieve anatomic compression to optimize healing.

Pitfalls
- Insufficient evaluation of the tear may lead to misclassification of the tear and inappropriate selection of the repair technique.
- Failure to adequately release a tight medial compartment via medial collateral ligament lengthening may result in iatrogenic injury to the chondral surfaces during implant passage.
- For type IV and V tears, failure to release the anterior and posterior fragments along the meniscocapsular junction may result in malreduction or inability to achieve compression across the tear site, increasing the potential for repair failure.
- In the event of a concomitant anterior cruciate ligament reconstruction, use of a transtibial tunnel for type III, IV, and V medial meniscus repairs may result in tunnel convergence.
- Premature weightbearing postoperatively may lead to failure with displacement and damage to the repair site.

Table 4. Advantages and Disadvantages

Advantages

- The proposed repair techniques focus on an easily identifiable set of tear patterns, with reproducible repair techniques aimed at anatomic restoration and compression along the extent of the tear to optimize repair healing.
- For type III, IV, and V tears, vertical mattress sutures positioned parallel to the meniscal tear are crucial to improve loads to failure for sutures placed perpendicular to the tear, acting as a "rip-stop" and decreasing the potential for tear displacement and failure.

Disadvantages

- Using an inside-out repair technique may inadvertently lead to injury to nearby neurovascular structures (saphenous nerve medially, peroneal nerve laterally), while necessitating a larger incision, increasing the potential for infection and wound-healing complication. For these reasons, the senior author prefers an all-inside repair technique when appropriate.

3 mm. In appropriately selected patients and compartment conditions amenable to healing, meniscal repair is recommended. Due to fragment displacement, release of the anterior and posterior fragments along the meniscocapsular junction is necessary to achieve an optimal reduction. When indicated, an arthroscopic scissor may be used to release the meniscus along the meniscocapsular junction. Care must be taken to avoid injury to the deep capsule or meniscal tissue. Meniscal excursion is checked using an arthroscopic grasper to reapproximate the meniscal fragments to their anatomic position, after which, the meniscal edges are gently debrided and rasped. A reduction stitch is then used to approximate the edges of the meniscus, and the construct is reinforced with a hashtag configuration in the same fashion as that described for type IV tears.

Transtibial Tunnels for Medial Meniscus Tear Types III, IV, and V

When addressing type III, IV, and V tears on the medial side, transtibial drill tunnels and suture fixation may be used to aid in reducing meniscal extrusion. For type IV and V tears, once the fragments are appropriately mobilized and positioned in their native anatomic location, and the edges have been debrided and rasped, a curved ring curette may be used to ensure removal of the cartilage under the inferior leaflet at the periphery of the tear. A meniscal root aiming guide (Smith & Nephew) is then positioned through the ipsilateral compartment (anteromedial portal for medial tears) and a 2-cm incision is created along the anteromedial aspect of the proximal tibia, positioned midway between the tibial tubercle and the posteromedial border of the tibia. A 2.4-mm drill pin is then passed using a cannula through the tibia and chondral surface at the level of the tear, near the meniscocapsular junction. The metal cannula is gently malleted into place, the drill pin is removed, and a passing suture is placed through the transtibial tunnel. An arthroscopic cannula is then placed within the ipsilateral compartment portal, and a self-capture suture-passing device (FirstPass; Smith & Nephew) is used to place a 2-0 nonabsorbable meniscal suture (FiberWire; Arthrex) in a horizontal mattress fashion through the posterior and anterior fragments of the radial tear near the periphery. The sutures are then shuttled down through the transosseous tunnel using a looped passing wire, and appropriate tensioning is visually confirmed. The sutures are then fixed to the anteromedial tibial cortex using a suture anchor (FootPrint Suture Anchor; Smith & Nephew). Once satisfactory reduction is achieved, a hashtag technique, as detailed above, can be used.

Discussion

While multiple types of meniscal tears have been observed, radial tears represent a unique subtype that has traditionally been associated with a poor prognosis.[13,18] Radial tears are often encountered in the acute traumatic setting in young patients or as a result of degenerative processes in older patients, especially involving the medial meniscus.[13] As a result of damage sustained to the circumferential fibers in radial tears, a substantial loss of meniscal function occurs, leading to decreased contact area and increased dynamic contact pressures,[19,20] resulting in a functionally meniscal-deficient state.[21-23] With resultant meniscal extrusion and the potential for tear progression, radial tears possess a high risk for subsequent chondral damage and early OA development.[13,14,24]

As radial tears were originally believed to not be amendable to repair, partial meniscectomy was traditionally regarded as the preferred surgical technique in patients with symptomatic radial tears of the meniscus.[10,25,26] However, debridement of radial tears has been shown to result in inferior biomechanical outcomes,[5,6] perpetuating a meniscal-deficient state and leading to early OA development.[7,9] Using a 3-dimensional model, Zhang et al.[27] observed a significant increase in compressive and shear stresses in the knee following meniscectomy, especially in cases in which radial tears were present. As such, with recent advancements in surgical techniques, equipment, and understanding of meniscal function following meniscectomy in the setting of radial tears, increased emphasis has been placed on preserving meniscal tissue through repair, when clinically indicated.

Operative repair is indicated in patients sustaining acute, traumatic tears, as well as in the setting of chronic, degenerative tearing in which adequate meniscal tissue remains and advanced degenerative changes are absent. Specifically, relative contraindications to radial meniscal repair include patients with joint space narrowing (<3 mm), as well as the presence of Kellgren-Lawrence grade ≥3 or modified Outerbridge grade >3 chondral degeneration, especially along both the femoral and tibial cartilage.[28] As such, in appropriately indicated cases, the repair of radial tears has shown promising outcomes, with healing rates ranging from 60% to 86%.[4] In a recent systematic review evaluating 12 studies, consisting of 243 tears in 241 patients, Milliron et al.[18] reported improved outcomes in Lysholm, International Knee Documentation Committee, and Western Ontario and McMaster's University scores, with complete healing reported in 62% of cases at a mean follow-up of 35 months (range, 12-75.6 months). Meanwhile, the systematic review by Moulton et al.[29] evaluating 6 studies in 55 patients observed improvements in subjective outcome scores at a minimum 2-year follow-up. Additional investigations have further revealed that repair of radial tears allows for effective return to function and activity through improvements in Tegner activity scores.[30,31]

Optimal repair technique for radial meniscus tears remains largely unknown, with studies reporting satisfactory repair achieved using multiple techniques and approaches. In their review of 6 studies examining repair characteristics for the treatment of radial tears in the midbody of the lateral meniscus, Alentorn-Geli et al.[32] reported no significant differences in load to failure when comparing all-inside vs inside-out ($P = .45$) techniques, with significantly greater repair stiffness following all-inside repair ($P = .0009$). Accordant with the senior author's preferred technique, the use of all-inside implants has gained popularity, owing to improvements in implant design and technique, with repairs being less technically demanding, while avoiding the need for a separate incision, minimizing the risk for injury to the surrounding neurovascular structures.[33] Additional investigations have shown all-inside repair to possess comparable biomechanical strength, stability, and healing capacity when compared to inside-out and outside-in techniques.[34-36] As described in the treatment of type III, IV, and V tears, the incorporation of vertical mattress sutures positioned perpendicularly to the circumferential fibers of the meniscus improves loads to failure, decreasing displacement and increasing stiffness when compared to horizontal, inside-out repair configurations. The ability to incorporate a rip-stop pattern further minimizes the risk for suture cut-out through the meniscus during placement of horizontal mattress sutures, improving meniscal healing capability when compared to nonreinforced construct patterns (Table 4).[34,36,37] In their systematic review examining 20 studies comparing biomechanical properties of various repair techniques for radial tears, Oosten et al.[34] reported that the all-inside, double vertical suture technique with horizontal reinforcing stitches exhibited increased load to failure and stiffness when compared to inside-out repairs. While mid- and long-term clinical outcomes studies following radial meniscal tears are lacking, incorporation of transtibial pullout augmentation has revealed the ability to reduce gapping at the site of the tear, improving load to failure and displacement.[38,39]

Diagnostic classification for radial tears is important as successful healing is largely dependent on the extent of peripheral tearing and the intrinsic ability for meniscal healing when repair is performed in the appropriately indicated patient. Nakata et al.[40] previously proposed a classification system for radial meniscal tears based on tear morphology. Type A tears were classified as split tears extending <50% of the width of the peripheral rim. Type B1 tears included radial split tears extending greater than 50% of the meniscal width, with B2 tears consisting of a radial split and flap component. Type C included complete radial split tears extending to the peripheral rim, while type D tears consisted of a radial split and associated bucket-handle component closer to the peripheral rim. Our currently proposed classification system builds on the classification system by Nakata et al.,[40] but focusing on the peripheral extent of the tear, imperative for successful healing,[41] as well as the presence of gapping, which may result in inferior outcomes if not properly identified and reduced.[42] Further investigations examining clinical outcomes and meniscal healing based on the proposed classification system are warranted to better understand and formulate an optimal treatment algorithm for patients with radial meniscal tears.

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